

## Anomalous Performance of a Near-Infrared Beamsplitter

5 July 2003

Prepared by

R. J. RUDY  
Space Science Applications Laboratory  
Laboratory Operations

J. D. BARRIE  
Space Materials Laboratory  
Laboratory Operations

Prepared for

SPACE AND MISSILE SYSTEMS CENTER  
AIR FORCE SPACE COMMAND  
2430 E. El Segundo Boulevard  
Los Angeles Air Force Base, CA 90245

Engineering and Technology Group

This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. F04701-00-C-0009 with the Space and Missile Systems Center, 2430 E. El Segundo Blvd., Los Angeles Air Force Base, CA 90245. It was reviewed and approved for The Aerospace Corporation by J. A. Hackwell, Principal Director, Space Science Applications Laboratory. Michael Zambrana was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

A handwritten signature in cursive script, reading "Michael Zambrana". The signature is written in dark ink and is positioned above the printed name and title.

Michael Zambrana  
SMC/AXE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</small>					
1. REPORT DATE (DD-MM-YYYY) 05-07-2003		2. REPORT TYPE		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE  Anomalous Performance of a Near-Infrared Beamsplitter		5a. CONTRACT NUMBER F04701-00-C-0009		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER		5d. PROJECT NUMBER	
		5e. TASK NUMBER		5f. WORK UNIT NUMBER	
6. AUTHOR(S)  R, J. Rudy, J. D. Barrie		7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  The Aerospace Corporation Laboratory Operations El Segundo, CA 90245-4691		8. PERFORMING ORGANIZATION REPORT NUMBER  TR-2003(8570)-9	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Space and Missile Systems Center Air Force Space Command 2450 E. El Segundo Blvd. Los Angeles Air Force Base, CA 90245		10. SPONSOR/MONITOR'S ACRONYM(S) SMC		11. SPONSOR/MONITOR'S REPORT NUMBER(S) SMC-TR-03-21	
		12. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution unlimited.			
13. SUPPLEMENTARY NOTES					
14. ABSTRACT  This document describes an anomaly in the performance of a custom beamsplitter designed and fabricated by one of the major coatings vendors. Specifically, the beamsplitter exhibited a true absorption in the reflective portion of its wavelength range. The absorption was not detected initially by the vendor or the end user because only transmission acceptance tests were performed. This is not uncommon since transmission measurements are frequently easier to perform and because reflectance and transmittance are assumed to be related by the simple formula: $\text{reflectance} = 1 - \text{transmittance}$ . This relation does not account for absorption, however, and the problem with this particular beamsplitter was not uncovered until it was installed into its host instrument. The lesson here is to acceptance check any beamsplitter over its full wavelength range in both reflection and transmission, testing it as it will be used.					
15. SUBJECT TERMS  Optical Coatings, Infrared Instrumentation					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES  7	19a. NAME OF RESPONSIBLE PERSON Richard Rudy
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (include area code) (310)336-5799

## **Acknowledgments**

We wish to thank Dr. J. Potter and D. Grenier at Barr Associates for their help in investigating the anomaly and for correcting it. Dr. M. Meshishnek is thanked for providing some of the transmission measurements. This work was supported by the US Air Force Space and Missile Systems Center through the Mission-Oriented Investigation and Experimentation program, under contract F4701-00-C-0009.

## Contents

1. Background.....	1
2. The Beamsplitter .....	3
3. Summary.....	7

## Figures

1. Predicted transmittance from the beamsplitter design .....	3
2. Predicted reflectance from the beamsplitter design .....	3
3. Measured transmittance of the beamsplitter as delivered.....	4
4. Measured reflectance of the beamsplitter as delivered .....	5
5. Measured transmittance after recoating.....	6
6. Measured reflectance after recoating.....	6

## 1. Background

The beamsplitter that is the subject of this technical report was an essential part of a spectrograph developed at Aerospace to cover the near-infrared (NIR) wavelength region. It was designed to accommodate two independent spectrographic channels, reflecting light from 0.8–1.35  $\mu\text{m}$ , transmitting light from 1.4–2.5  $\mu\text{m}$ , and transitioning from reflective to transmissive in the interval between 1.35 and 1.4  $\mu\text{m}$  (a region that is largely opaque due to absorption by atmospheric water vapor).

The light incident on a beamsplitter (or any material) can be accounted for by Kirchhoff's equation that relates absorbance ( $\alpha$ ), reflectance ( $\rho$ ), and transmittance ( $\tau$ ):

$$\alpha + \rho + \tau = 1.$$

This is simply a statement of conservation of energy—the energy impinging must be transmitted, reflected, or absorbed, and the various portions must total to what is incident. In the case of non-absorbing (lossless) materials the relation simplifies to

$$\rho + \tau = 1.$$

Tacit in design and fabrication of many coated optics is the assumption that over the operational range light is either reflected or transmitted but not absorbed. Under this assumption a beamsplitter can be completely characterized by a transmission measurement alone. In practice, this may considerably simplify testing since reflectance measurements frequently involve more elaborate preparations and cumbersome geometries. This was the course followed for the beamsplitter under discussion—we describe below the problems that resulted.

## 2. The Beamsplitter

Figures 1 and 2 show the theoretical performance of the beamsplitter as designed.

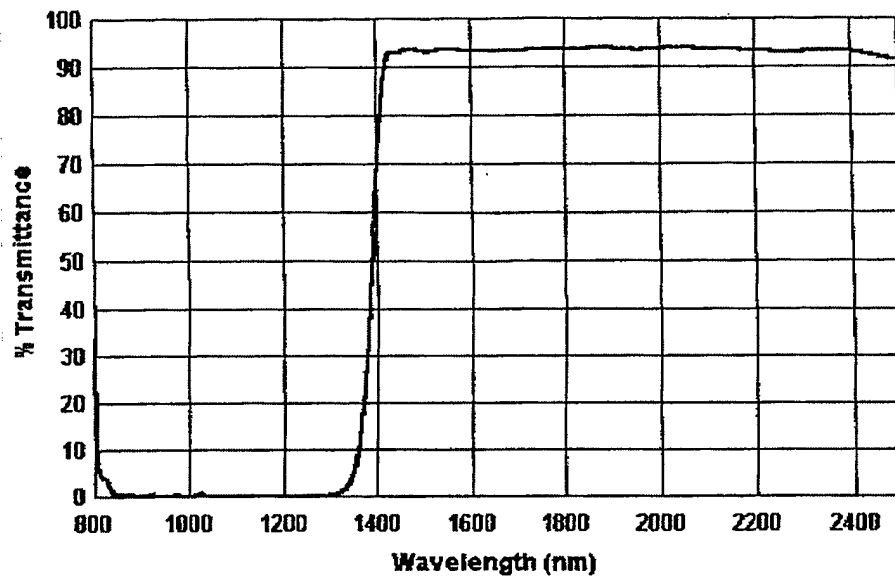


Figure 1. Predicted transmittance from the beamsplitter design. Note that the predicted transmission is very close to 1 – reflectance shown in Figure 2.

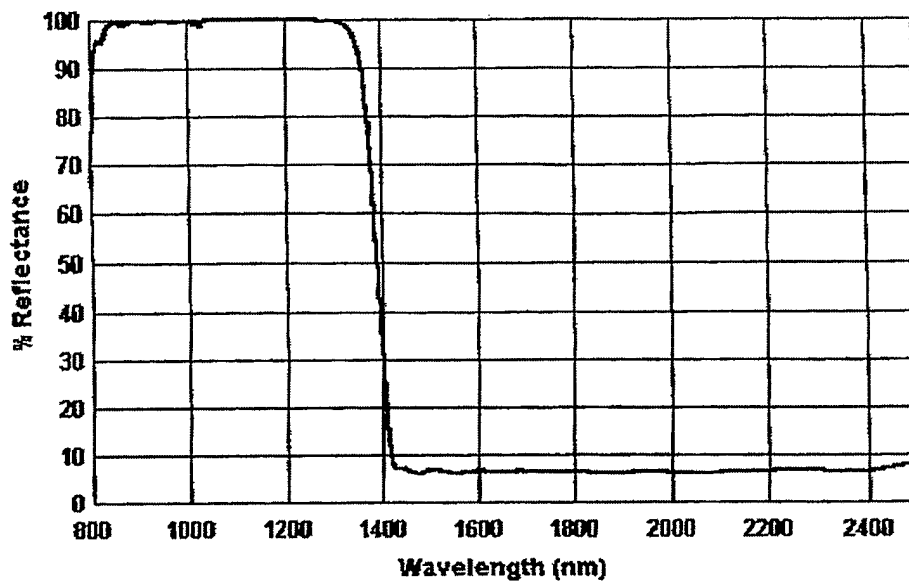


Figure 2. Predicted reflectance from the beamsplitter design. Note that the predicted reflectance is very close to 1 - transmittance shown in Figure 1.

What can be seen is that the reflectance and transmittance are very nearly given by the lossless form of Kirchhoff's equation, that is  $\rho + \tau = 1$ . Moreover the performance is fairly close to ideal. The reflectance is nearly 100% for almost all of the 0.8–1.35  $\mu\text{m}$  range (800–1350 nm), and the beamsplitter switches rapidly from reflecting to transmitting in the 1.35–1.40  $\mu\text{m}$  interval. Only the performance beyond 1.4  $\mu\text{m}$  is significantly less than optimum, showing a spectrally flat reflectance of ~7% that comes at the expense of the desired transmittance. Expectations for the actual fabricated beamsplitter were for slightly reduced performance since the theoretical design does not account for deviations in the thickness of the deposited layers nor in the broadband anti-reflective coating on the reverse side of the substrate that improves the transmission beyond 1.4  $\mu\text{m}$ .

The beamsplitter, as first built and delivered, had the transmissive and reflective properties displayed in Figures 3 and 4.

From Figure 3 it can be seen that the transmittance behaved as expected from the predicted performance. Unfortunately, transmittance was the only parameter measured, both by the vendor before shipping, and by Aerospace personnel upon receipt. The reflectance measurement of Figure 4 was not acquired until after the beamsplitter had been installed into the spectrograph. The anomalous behavior is the unwanted oscillations in the reflectance in the interval 0.85–1.05  $\mu\text{m}$ . Because there are no corresponding features in the transmittance curve, these features signify true absorption by the beamsplitter.

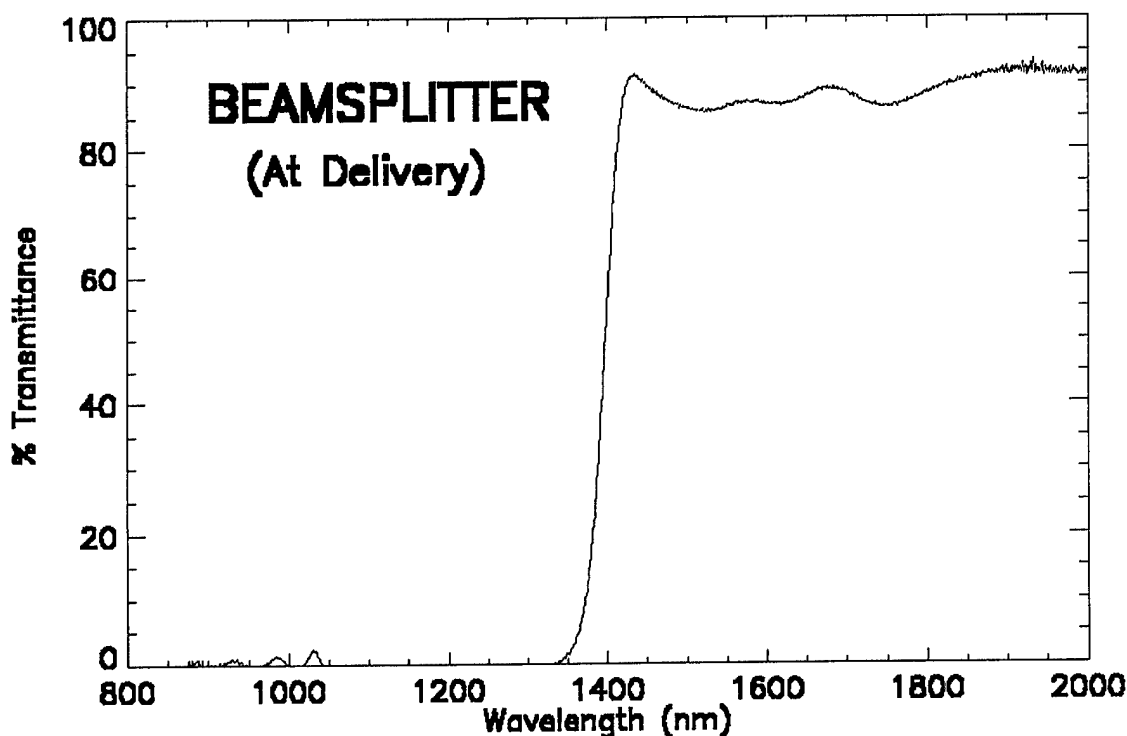


Figure 3. Measured transmittance of the beamsplitter as delivered. Note that this is very close to the theoretical transmission; there is no evidence of any anomaly apparent.



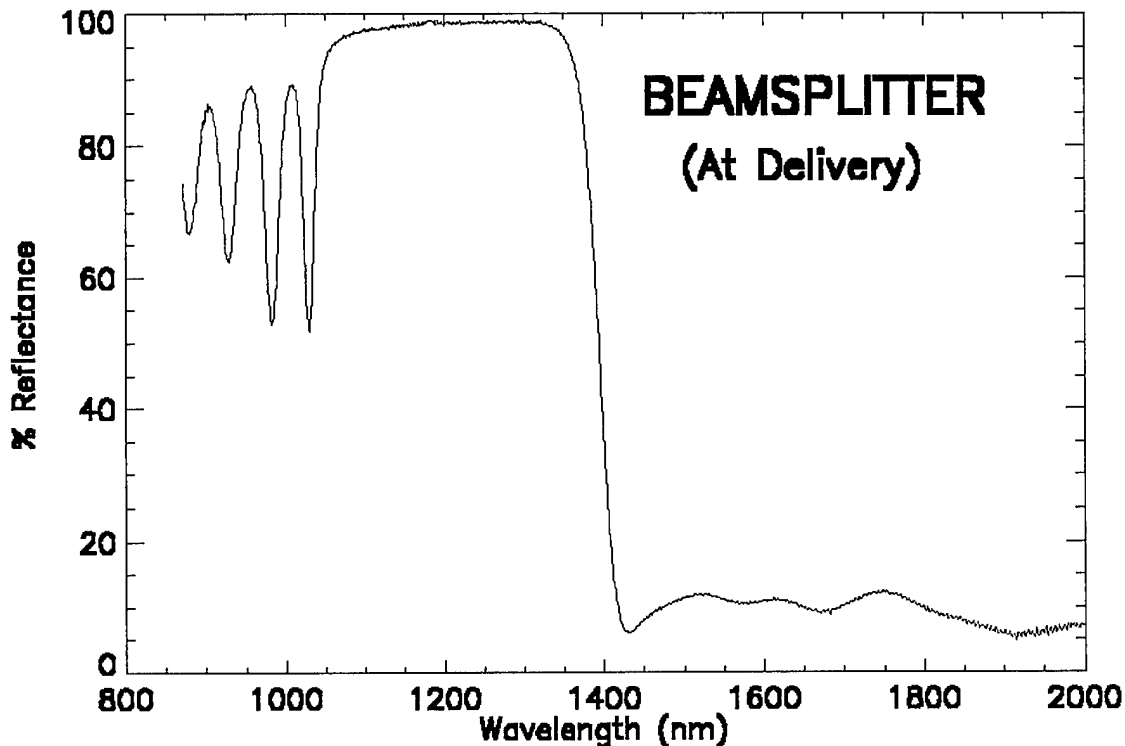


Figure 4. Measured reflectance of the beamsplitter as delivered. The anomalous behavior of the beamsplitter is the absorption features between 0.9  $\mu\text{m}$  and 1.0  $\mu\text{m}$ . The absence of matching features in the transmission spectrum (Figure 3) indicates these are true absorptions. Note that the reflectance is relative to spectralon rather than absolute. However, the reflectance of spectralon is believed to be >99% over this wavelength range.

What was so unexpected about these features, and the reason for the assumption that the lossless form of Kirchhoff's equation was applicable and that beamsplitter performance could be verified by measuring transmittance only, is that none of the materials used in the fabrication of the beamsplitter exhibit absorption in the near-infrared. These included the substrate (sapphire) and the high-index ( $\text{Nb}_2\text{O}_5$ ) and low index ( $\text{SiO}_2$ ) coating materials. The designer of the coating (at the vendor) thought that there may have been contamination by water vapor of one or more of the layers. However, a subsequent effort to drive off this water through a bake-out procedure failed so we cannot confirm that this was the problem.

The problem was eventually resolved by adding an additional layer to the coating. The transmittance and reflectance that resulted are illustrated in Figures 5 and 6.

As can be seen from Figure 6, the oscillations between 0.85 and 1.05  $\mu\text{m}$  are gone. However, the downside is that that additional layer added an unwanted reflection around 1.5  $\mu\text{m}$ , reducing the light transmitted to the red channel of the spectrograph. If the beamsplitter has been screened for reflectance upon the initial reception, and thus never passed the acceptance testing, it is probable that the part may have been stripped and recoated from scratch. A superior beamsplitter would have resulted.

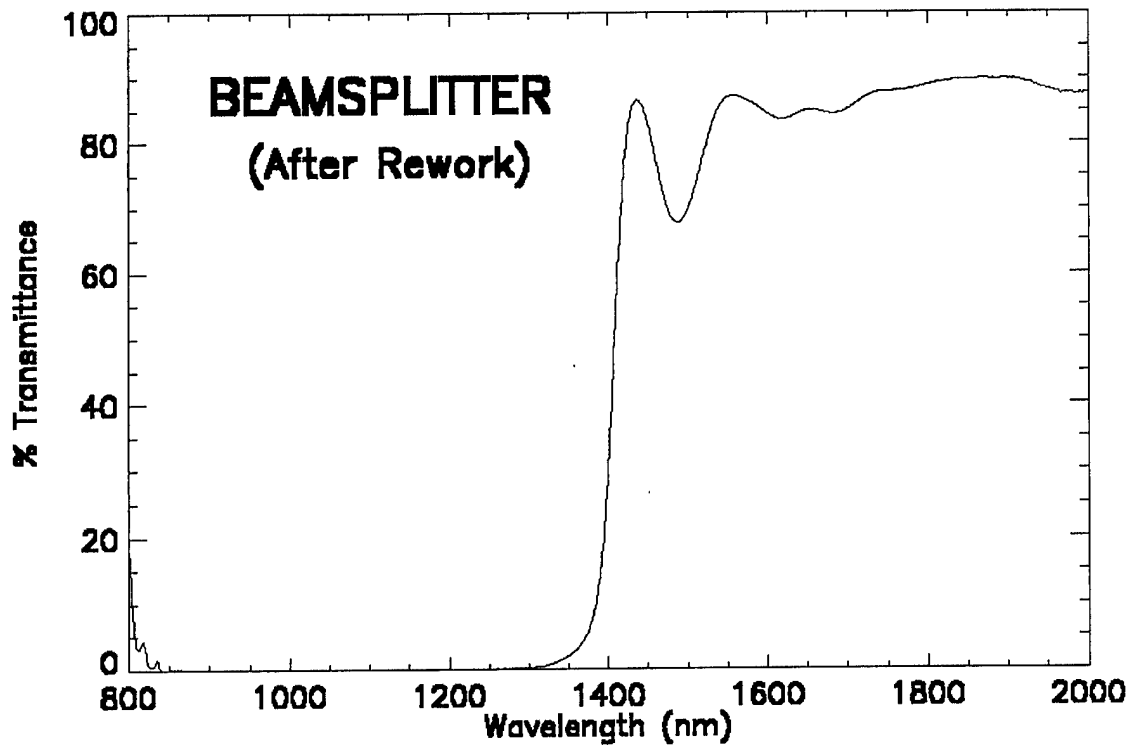


Figure 5. Measured transmittance after recoating.

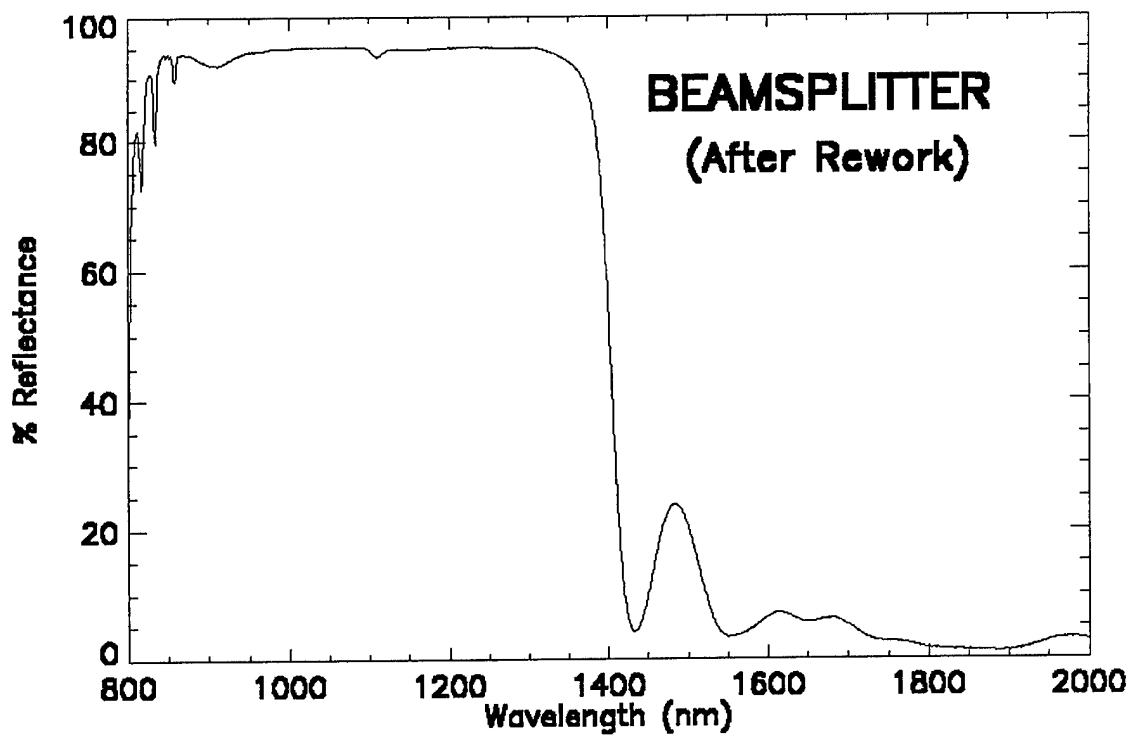


Figure 6. Measured reflectance after recoating.

### 3. Summary

This document has reported on an entirely unexpected but detrimental absorption exhibited by a beamsplitter that was commissioned for a research spectrograph operating in the near-infrared. This anomalous behavior would have been detected by a more rigorous testing program, both by the vendor and here at Aerospace. It is recommended that any beamsplitter purchased have *both its transmittance and reflectance* measured over the entire wavelength region for which it will be used.

## LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Laboratory Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual organizations:

**Electronics and Photonics Laboratory:** Microelectronics, VLSI reliability, failure analysis, solid-state device physics, compound semiconductors, radiation effects, infrared and CCD detector devices, data storage and display technologies; lasers and electro-optics, solid-state laser design, micro-optics, optical communications, and fiber-optic sensors; atomic frequency standards, applied laser spectroscopy, laser chemistry, atmospheric propagation and beam control, LIDAR/LADAR remote sensing; solar cell and array testing and evaluation, battery electrochemistry, battery testing and evaluation.

**Space Materials Laboratory:** Evaluation and characterizations of new materials and processing techniques: metals, alloys, ceramics, polymers, thin films, and composites; development of advanced deposition processes; nondestructive evaluation, component failure analysis and reliability; structural mechanics, fracture mechanics, and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle fluid mechanics, heat transfer and flight dynamics; aerothermodynamics; chemical and electric propulsion; environmental chemistry; combustion processes; space environment effects on materials, hardening and vulnerability assessment; contamination, thermal and structural control; lubrication and surface phenomena. Microelectromechanical systems (MEMS) for space applications; laser micromachining; laser-surface physical and chemical interactions; micropropulsion; micro- and nanosatellite mission analysis; intelligent microinstruments for monitoring space and launch system environments.

**Space Science Applications Laboratory:** Magnetospheric, auroral and cosmic-ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; infrared surveillance, imaging and remote sensing; multispectral and hyperspectral sensor development; data analysis and algorithm development; applications of multispectral and hyperspectral imagery to defense, civil space, commercial, and environmental missions; effects of solar activity, magnetic storms and nuclear explosions on the Earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation, design, fabrication and test; environmental chemistry, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions, and radiative signatures of missile plumes.